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GEANT simulations for flight path 14 – follow-up

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Abstract

This report is a follow-up of Reifarth et al. [1]. The motivation for this report is a new design of the last collimator of the Detector for Advanced Neutron Capture Experiments (DANCE) at flight path (FP) 14. a 20 m neutron flight path, which views the "upper tier" water moderator at the Manuel J. Lujan Jr. Neutron Scattering Center at the Los Alamos Neutron Science Center. The present design was not investigated in the previous report.
The response of the collimation system to neutrons and gamma rays was studied using the Monte Carlo code GEANT 3.21. [2] for different shapes of the last collimator.

1 Geometry

The overall geometry as well as the Calculational approach remained the same as in the first report [1]. Only the last collimator was changed.

The last collimator is about 100 times longer than wide. This implies a crucial influence of the shape of the inner diameter to the collimation. Additionally, the inner set of this collimator can be changed without major constructions at the flight path, since it is accessible from the experimental room after removing the vacuum system. The changes investigated within this report affect only the inner diameters of the different layers of the last collimator. The thicknesses as well as the materials were left unchanged. Figure 1 provides a schematic view of the different simulated shapes. The straight version was realized in October 2002, while the biconical version is in place since May 2003. Both so far realized solutions reduce not only the neutron flux outside the nominal sample radius, but also the neutron flux at very small sample radii. The reason for this reduction is that the collimator is so small, that no point at the sample position is irradiated by the whole neutron target (moderator).

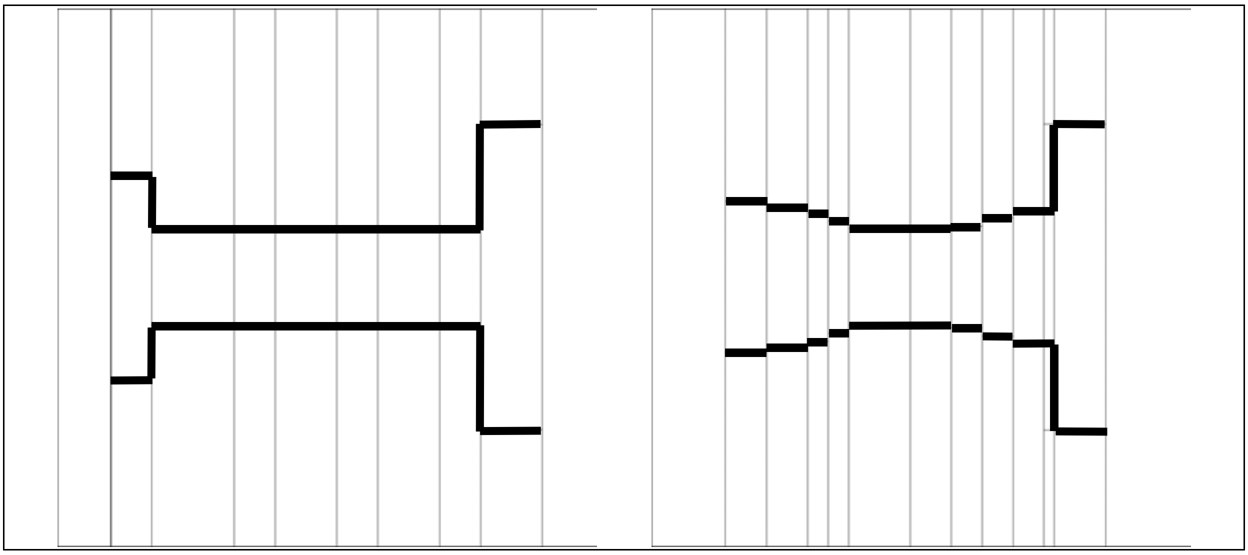

Figure 1: Schematic view of the two different configurations of the last collimator. The neutrons are traveling from left to right. The thick lines correspond to the shape of the hole inside the collimator. The details of the straight (left), and the small biconical (right) shape are described in the text. Both versions contain so-called "clean up" collimators. Such collimators are frequently used and have a greater radius than the nominal beam radius at the actual position.

The details about the two different shapes of the last collimator are listed in Table 1 and Table 2 and shown in Figure 2 and Figure 3.

Table 1: Fourth collimator, straight realization. The center of the collimator is 1849.85 cm away from the neutron production target. The total length is 106.7 cm. All position numbers in the table are relative to the center of the collimator.

Pos. Upstream (cm)	Pos. Downstream (cm)	Thickness (cm)	Outer radius (cm)	Inner Radius upstream (cm)	Inner Radius downstream (cm)	Material
-53.35	-43.15	10.2	15	0.635	0.635	B-PE
-43.15	-22.85	20.3	15	0.300	0.300	Cu
-22.85	-12.75	10.1	15	0.300	0.300	B-PE
-12.75	2.55	15.3	15	0.300	0.300	Cu
2.55	12.65	10.1	15	0.300	0.300	B-PE
12.65	27.95	15.3	15	0.300	0.300	Cu
27.95	38.05	10.1	15	0.300	0.300	B-PE
38.05	53.35	15.3	15	0.950	0.950	Cu

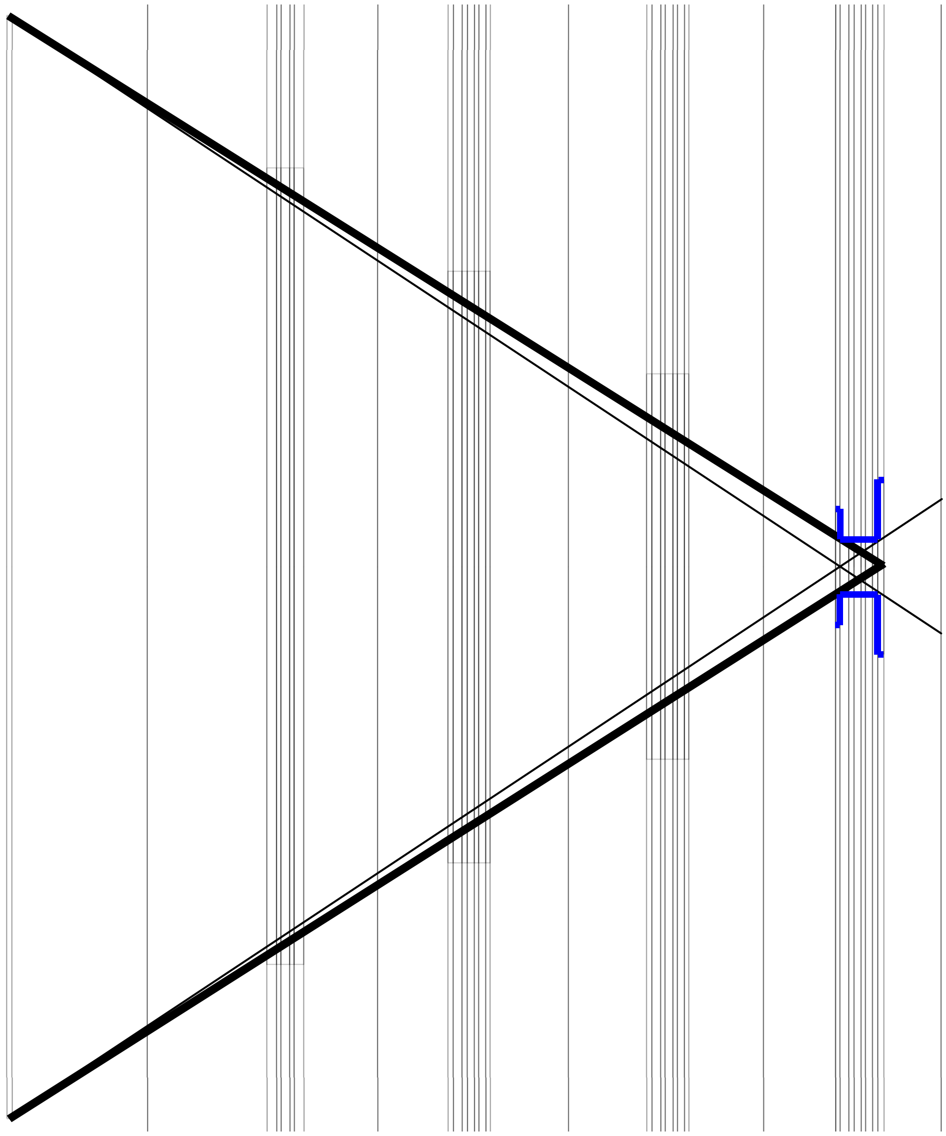

Figure 2: Sketch of the whole beam line with the straight collimator. The vertical axis is magnified by a factor of 200, otherwise the drawing is on scale. The inner shape of the last collimator is shown in blue. The thick black line corresponds to the umbra, while the slightly thinner black line shows the penumbra. Obviously the whole sample position (last single line to the right) is in the penumbra region.

Table 2: Fourth collimator, conical realization. The center of the collimator is 1849.85 cm away from the neutron production target. The total length is 96.5 cm. All position numbers in the table refer to the center of the collimator.

Pos. Upstream (cm)	Pos. Downstream (cm)	Thickness (cm)	Outer radius (cm)	Inner Radius upstream (cm)	Inner Radius downstream (cm)	Material
-48.25	-38.05	10.2	15	0.469	0.469	Cu
-38.05	-27.95	10.2	15	0.433	0.433	Cu
-27.95	-22.85	5.1	15	0.400	0.400	B-PE
-22.85	-17.75	5.1	15	0.350	0.350	B-PE
-17.75	-2.55	15.2	15	0.300	0.300	Cu
-2.55	7.65	10.2	15	0.300	0.300	B-PE
7.65	15.25	7.6	15	0.317	0.317	Cu
15.25	22.85	7.6	15	0.367	0.367	Cu
22.85	33.05	10.2	15	0.411	0.411	B-PE
33.05	48.25	15.2	15	0.452	0.452	Cu

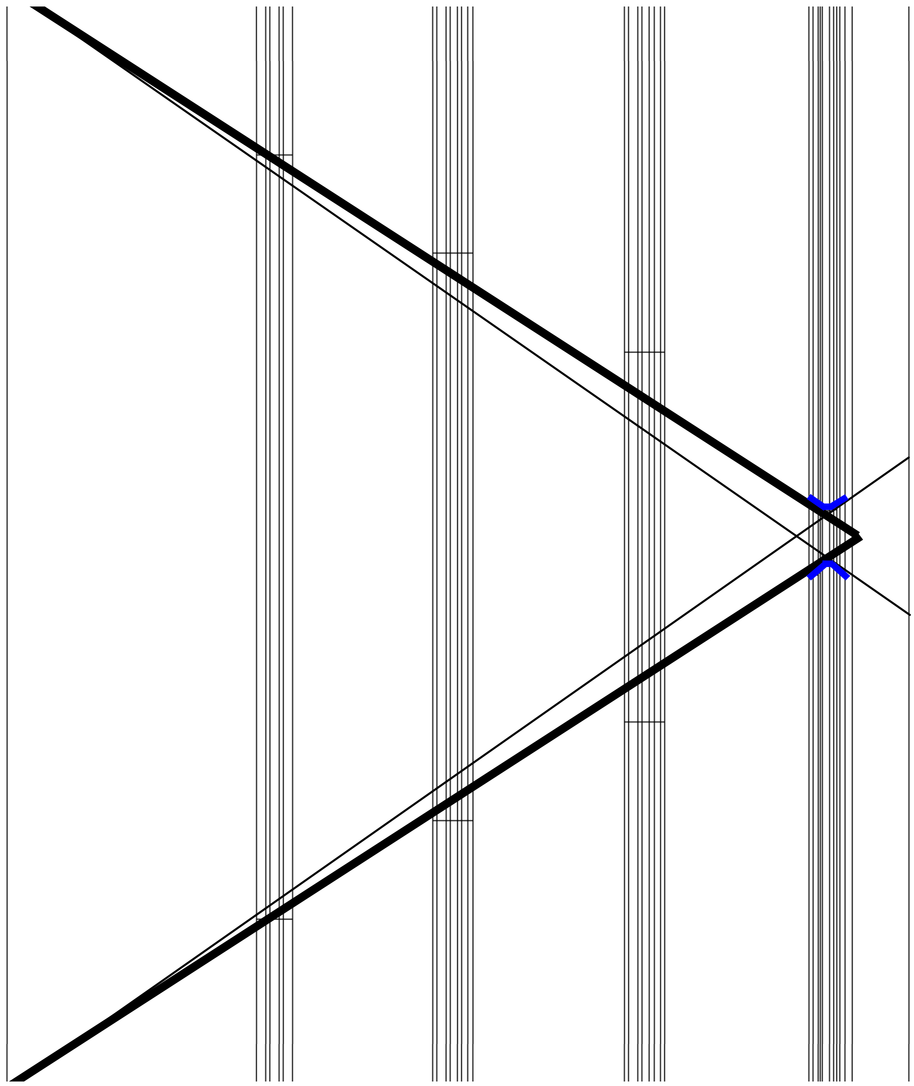

Figure 3: Sketch of the whole beam line with the conical collimator. The vertical axis is magnified by a factor of 200, otherwise the drawing is on scale. The inner shape of the last collimator is shown in blue. The thick black line corresponds to the umbra, while the slightly thinner black line shows the penumbra. The inner part of the sample position (last single line to the right) is in the umbra region and has therefore a constant neutron flux.

2 Simulations with γ-rays

Low energetic γ-rays of 55 keV have been traced starting at the position of the neutron moderator. Whenever these photons interact with the beam pipe or with the collimators their energy falls below the GEANT-internal cut-off energy of 50 keV and they are not traced anymore. The results of these simulations can therefore be interpreted as images of the neutron target seen at different positions along the flight path.

2.1 Different geometries for collimator 4

Figure 4 shows the results of all 4 different versions of the last collimator. 10^8 γ-rays have been started at the position of the neutron target. Please see again [1] for details on the geometries "biconical big" and "conical". The gammas were emitted uniformly from a disk with a radius of 6 cm, which corresponds approximately to the size of the water moderator, which acts as the neutron emission area for FP14. In order to save CPU-time, the emission angle relative to the direction of the beam line was restricted to 0.5 degrees, which means, that the maximum travel of the gammas perpendicular to the beam line is a 17 cm for 20 m flight path. With a nominal sample radius of 0.25 cm, all versions show a plateau of constant number of gammas per area up to 0.4 cm, which is preferable, since the mass distribution of the sample might not be uniform. The gamma flux of the conical realizations is increased by a factor of 4.5 compared to the straight version. The trade off is an increased halo-region: 1.3 cm compared to 0.8 cm. The beam profiles of the two different conical solutions are the same up to 1 cm radius, while the outer halo region of the biconical version is somewhat bigger than the one of the conical version. This implies, that at this point the conical configuration is to prefer over the biconical one.

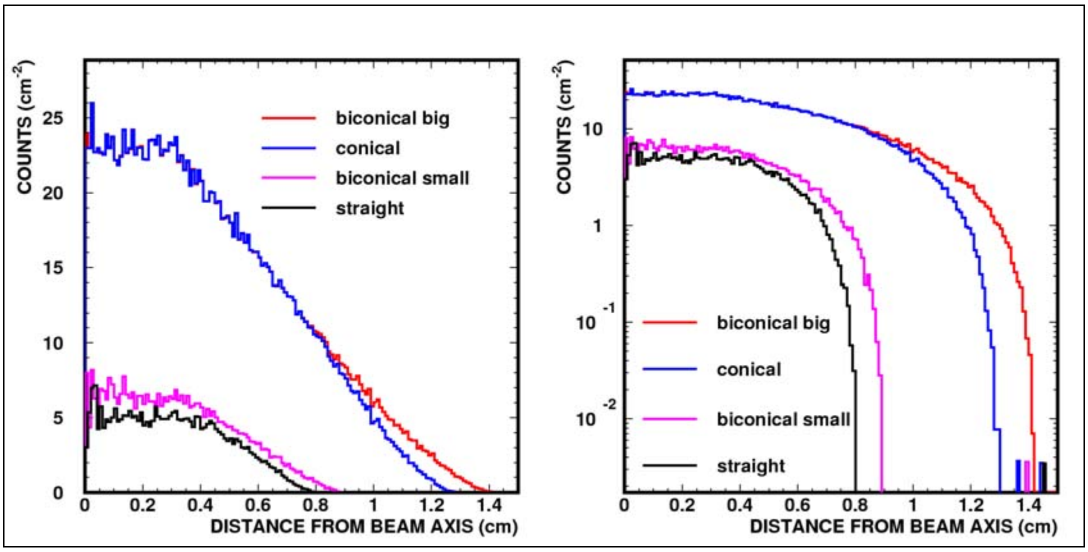

Figure 4: Results of simulations of γ-ray with energies of 55 keV. Both pictures contain the same data. The y-axis of the left one is linear, while the right one is in logarithmic scale. The details of the setups "biconical big" and "biconical small" are described in [1]. The setups "biconical small" / "straight" is/was actually realized at FP-14.

3 Simulations with neutrons

Neutrons don't behave like low energetic photons in a sense that they usually do not disappear after an interaction. The most likely interaction of a neutron with energies above 1 keV, and especially above 1 MeV, is elastic or inelastic scattering. Therefore additional simulations are needed in order to investigate these extra effects (please see also Sect. 3.2).

In a first attempt neutrons with an 1/E energy dependence were simulated. Starting at the neutron moderator 10^7 neutrons per decade between 1 eV and 100 MeV were emitted. The beam started with 6 cm radius and an opening angle of 0.5 degrees. High-energy neutrons showed a significant extra background component at the sample position. Therefore the results of low-energy neutrons will be discussed in the next section (3.1), while the high energetic neutrons will be discussed in section 3.2.

3.1 Low-energy neutrons

Neutrons below 100 keV will usually be stopped shortly after the first interaction. Since scattering cross sections as well as (n,x) cross sections increase very quickly with decreasing neutron energy, these neutrons will be stopped by producing γ-rays or charged particles very close to the first interaction point. Therefore the expected beam profile at the sample position is similar to the profile derived by simulating low energetic γ-rays. Figure 5 shows a representative result for neutrons with energies between 1 and 10 keV. A comparison with Figure 4 confirms the discussion above.

Since the situation will be different for high-energy neutrons, it is important to point out, that the neutron flux for distances greater than 1.5 cm from the center of the beam axis is reduced by more than 5 orders of magnitude.

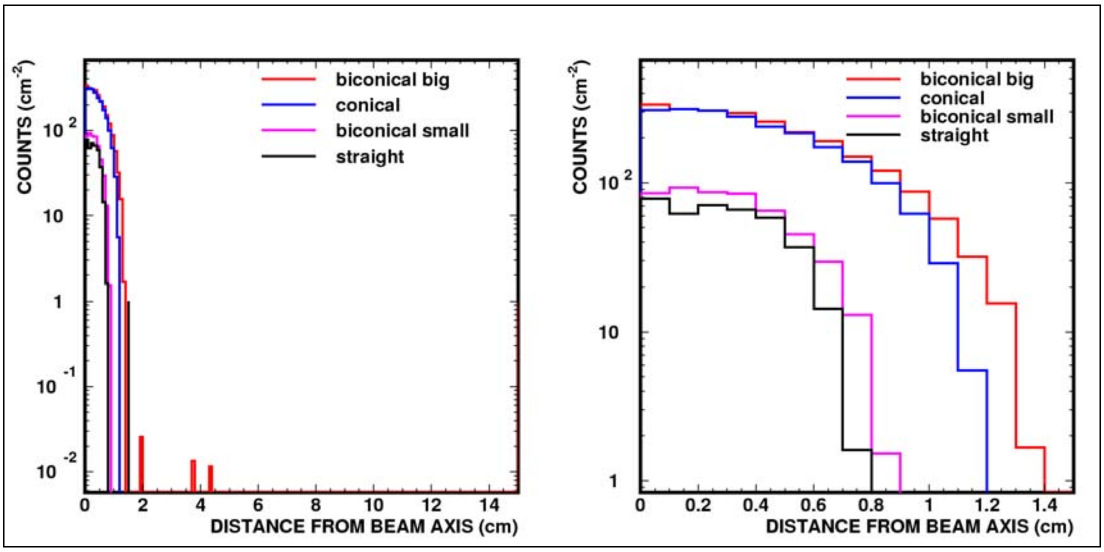

Figure 5: Results of simulations of neutrons with energies between 1 and 10 keV. Both pictures contain the same data. The x-axis of the left one shows the whole region of interest up to 15 cm radius, while the right one shows only the region very close to the neutron beam allowing to compare the neutron profiles at the sample position. 10^7 neutrons were started at the neutron moderator.

3.2 High-energy neutrons

Neutrons above 1 MeV are very difficult to shield. Depending on the material, the main interaction mechanism is elastic or inelastic scattering on nuclei. While the energy loss during inelastic neutron scattering can be significant, the cross sections are usually very small except for a small energy region just above the excitation energy of the respective nucleus. In contrary, elastic scattering cross sections are usually fairly big over a broad energy range, while the energy loss is very small. This implies, that a high energy neutron will interact many times before it will be captured eventually. Figure 6 shows the result of a simulation with neutrons between 10 and 100 MeV energy. In order to improve the statistics 10^8 neutrons were simulated. Obviously the beam profile close to the center of the beam is the same as for low energetic neutrons. However, with increasing distance to the beam center, the beam profile shows significant differences.

In the region between 1.5 and 5 cm a beam halo, with a neutron flux 3 to 4 orders of magnitude smaller than the flux in the center of the beam, appears. This beam halo originates from neutrons coming directly from the moderator and being scattered once inside the last collimator.

Another remarkable component appears at even higher radii. A flat plateau, with a neutron flux 5 orders of magnitude below the center flux, extends up to the highest simulated radius of 15 cm.

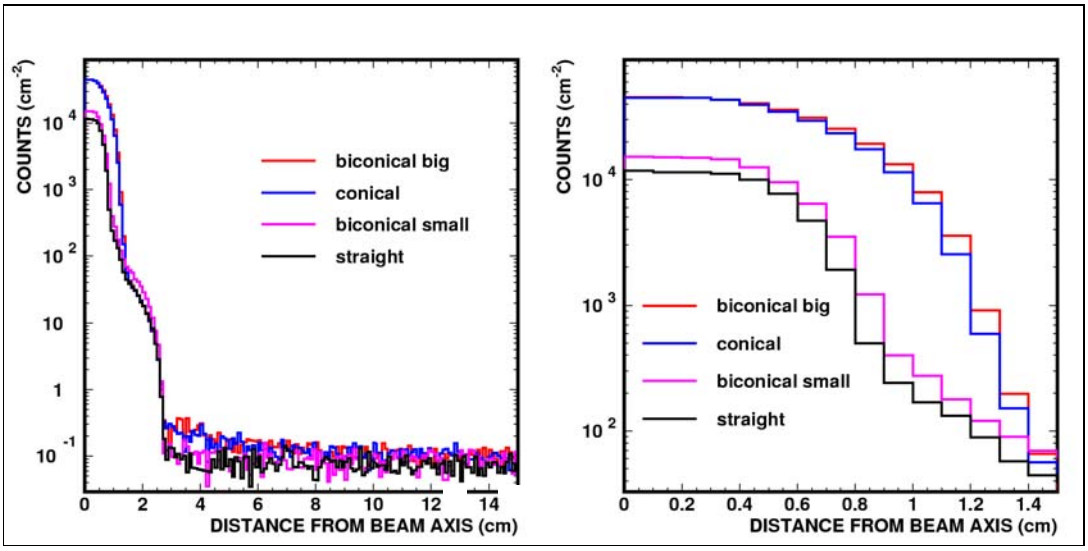

Figure 6: Results of simulations of neutrons with energies between 10 and 100 MeV. Both pictures contain the same data. The x-axis of the left one shows the whole region of interest up to 15 cm radius, while the right shows only the region very close to the neutron beam allowing to compare the neutron profiles at the sample position. 10^8 neutrons were started at the neutron moderator.

4 Conclusions

The presently mounted biconical version is expected to show about 30% more neutron flux than the previously used straight version at the plateau of the beam profile. The trade of is a slightly increased halo-radius of 0.9 compared to 0.8 cm.

Close to the target the conical geometries provide a neutron flux which is almost a factor of 5 higher than for the straight geometry. This would imply a significantly improved signal to not beam related background ratio as well as much improved statistics for the same run time. Both conical solutions show a broader beam profile than the straight one, the profile of the

single conical solution being slightly narrower. If the geometrical size of the sample is limited to a few millimeter, while the backing can not be made of the same size, a narrow beam halo might be more important than a higher neutron flux.
At a distance of more than 1.5 cm from the beam axis there is no difference between the all of the solutions anymore. Especially for high energetic neutrons the collimation of the last collimator has no influence.

5 References

1. Reifarth R., et al., *LANL Report*, **LA-UR-02-7695** (2002).
2. Apostolakis J., *CERN Report*, **W5013** (1993).